Evaluation of New Surface Preparation and Coating Repair Techniques in Ballast Tanks = Final Report

U.S. DEPARTMENT OF THE NAVY
DAVID TAYLOR RESEARCH CENTER

in cooperation with

National Steel and Shipbuilding Company
San Diego, California

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EVALUATION OF
NEW SURFACE PREPARATION AND COATING REPAIR TECHNIQUES IN BALLAST TANKS-FINAL REPORT

JANUARY 1993

PREPARED BY:
ASSOCIATED COATINGS CONSULTANTS
IN COOPERATION WITH
NATIONAL STEEL AND SHIPBUILDING COMPANY
SAN DIEGO, CALIFORNIA

Task No. N3-89-6 MOD

FOREWORD

This Research and Development project was performed under the National Shipbuilding Research Program (NSRP). The project, as a part of the program, is a cooperative cost shared effort between the Maritime Administration, the United States Navy, and National Steel and Shipbuilding Company (NASSCO). The research and development work was accomplished by Associated Coatings Consultants, Inc. under sub-contract to NASSCO. The overall objective of the program is improved productivity and therefore, reduced shipbuilding costs.

The study was undertaken toward this goal and followed closely the project outline approved by the Society of Naval Architects and Marine Engineers (SNAME) Ship Production Committee.

Mr. Lynwood Haumschilt of NASSCO was the National Shipbuilding Research Program (NSRP) Manager of Panel SP-3 at the inception of this program. As NSRP Manager, Mr. Haumschilt was responsible for technical direction and publication of the final report. Program definition and guidance was provided by the members of the SP-3 Surface Preparation and Coatings Subcommittee of the SNAME Ship Production Committee.

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EXECUTIVE SUMMARY

Ship ballast tanks offer unique corrosion control challenges. Being subjected to intermittent wet and dry cycles of aerated sea water places an extreme demand on corrosion control methods. Harsh service environments are coupled with necessarily complex tank geometries, especially in Navy combatants where weight and hull designs dictate small, irregular tanks with limited accessibility. These difficulties equate to costly corrosion control techniques. The NSRP SP-3 Panel recognized these problems and formulated a series of research and development projects to investigate alternate, cost effective corrosion control solutions for the preservation of ballast tanks.

The first project began in 1980 and was entitled "Cathodic Protection/Partial Coatings Versus Complete Coating in Tanks." A series of steel mock-up ballast tanks were constructed which duplicate tank geometries. The tanks were also large enough to allow access for surface preparation and installation of the various corrosion control methods. The testing results are contained in NSRP Reports 0158, 0205 and 0280.

In 1988, the project was redirected to evaluate maintenance procedures and techniques. At that time the tanks had been under test for six years. Included in the new project were current VOC compliant, surface tolerant epoxies from two suppliers, a new formulation of Mil-P-24441 VOC compliant epoxy, a soft coating, and a Japanese technique of adding a zinc anode (for cathodic protection) to an existing, partially failed coating in lieu of coating replacement. Two coating systems from the original project were still providing adequate protection and, therefore, left undisturbed. After three additional years of testing (nine years for some systems), all but one of the systems were still providing a degree of protection. The results of this project were reported in NSRP Report 0332.

In 1990, funding was approved to extend the project for an additional two years. This report contains the results of five years of testing under the new program. After eleven years of testing, the inorganic preconstruction primer with zinc anode has finally failed. The VOC compliant surface tolerant epoxy "A" applied over both the power tool cleaned and abrasive blast cleaned surfaces was essentially equal in performance for the first three years, but the power tool cleaned system was somewhat inferior after five years. Both systems require extensive repair. The same was true for the epoxy “B” except for the bottom of the hand cleaned tank which had excessive dry film thickness. The coating with the excessive thickness began to crack after one year and was totally delaminated at the end of three years. This coating and the same coating applied over abrasive blasted steel were repaired using hand and power tool cleaning techniques.

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CONCLUSIONS

This report includes the controlled testing results of new approaches to surface preparation and coating repair techniques for preservation of in-service ships ballast tanks utilizing VOC compliant coatings after five years of testing. Performance results are also included for other corrosion control techniques.

The project was originally initiated to test and evaluate the technical feasibility and economics of using a combination of cathodic protection and partial coatings in lieu of complete coatings of ballast tanks. Mock-up test tanks were constructed and coated to verify performance.

After concluding the initial test program, the SP 3 Panel Members decided to investigate the technical feasibility of reducing coating repair costs utilizing less costly surface preparation, i.e., hand and power tool cleaning, combined with surface tolerant coatings with special emphasis given to VOC compliant coatings. The new project consisted of replacing failed coatings with two different manufacturer's surface tolerant epoxy systems. Each system was applied over both hand and abrasive blast cleaned steel surfaces. Additional VOC compliant systems were also included in the test project. Systems tested included:

- VOC compliant surface tolerant epoxy "A" over Power Tool Cleaned (SSPC SP-3) surface
- Completely coated tank (previously in service for six years) with zinc anode being added
- Original partially coated tank with zinc anode (no repair required)
- VOC compliant surface tolerant epoxy "A" over abrasive blasted surface
- VOC compliant surface tolerant epoxy "B" over abrasive blasted surface (repaired after six years)
- Inorganic zinc preconstruction primer with anodes
- VOC compliant MIL-P-24441 over abrasive blasted surface
- Biodegradable soft coating
- VOC compliant surface tolerant epoxy "B" over solvent and hand tooled cleaned surface (repaired after three years)
- High ratio waterborne inorganic zinc

At the end of five additional years of testing (eleven for some systems) , the test results can be summarized as follows:

- The hand tool cleaned Epoxy “A” system was essentially equal in performance to the abrasive blast cleaned surfaces for the first three years but inferior after five years. Both coated tanks require extensive repairs or replacement after five years of testing.
- Except for areas of high film thickness which failed in the hand cleaned tank, Epoxy “B" performed equally well over both hand tooled and abrasive blast cleaned steel.
- Epoxy “B” applied over a “Commercial Blast Clean” (SSPC-SP 6) surface provided protection for six years.
- Excessive thickness of surface tolerant epoxies can result in premature coating failures due to cracking.
- Except for edges, the VOC compliant version of MIL-P-24441 provided acceptable corrosion protection for five years. Some failures can be attributed to poor application, i.e. difficult to reach areas not coated.
- The preconstruction primer with zinc anode provided eleven years of protection with no repairs .
- The preconstruction primer with aluminum anode provided five years of protection.
- The preconstruction primer without cathodic protection provided three years of protection.
- Partial coating (Mil-P-23236) with zinc anode system is still providing protection after eleven years with no repairs required.
- Partial coating (Mil-P-23236) with aluminum anode system provided six years of protection.
- Zinc anode addition to the six year old totally coated tank (Mil-P-23236) is providing extended protection without the necessity of coating repair/replacement.
- The use of cathodic protection with coatings compliments and improves the resultant performance of either system used individually.
- The biodegradable soft coating failed after one year.

1. PROJECT PLAN OF ACTION

1.1 Background Technical Information.

The original study and test program published in May 1982 with updates in 1985, 1987, 1990 and 1991 include detail discussions of various corrosion control techniques. Summarized below are some of the pertinent points of these reports.

1.1.1 Partial Coatings with Cathodic Protection

Sacrificial anode cathodic protection systems can be designed to provide extended protection; however, as the length of protection is increased, the weight of the anodes are necessarily increased. A practical limit is reached which balances the increased dead weight of the vessel being protected with cargo carrying capacity. With naval combatants, increased weight can be more significant. Based on these considerations, anode systems are generally designed to provide four to eight years of protection.

Cathodic protection systems do not perform satisfactorily on overhead surfaces due to air pockets. These areas are subject to severe corrosion. Another problem associated with the use of cathodic protection in salt water ballast tanks is created from the residual water and wet silt which accumulates on the tank bottom after de-ballasting. This salt muck provides a path for steel corrosion. Since the anodes are above the surface of the muck, no protection is provided.

To mitigate these problems, high performance coating systems are generally applied in conjunction with cathodic protection. Coatings are applied to the overhead surfaces to include six to twenty-four inches down each bulkhead and frames plus the tank bottoms to include six to twenty-four inches above the bottom. During ballast, the protective coating system protects the steel and supplements the cathodic protection system, therefore reducing anode consumption. During the de-ballasted portion of the cycle, the coatings protect the high corrosion areas. Being in sea water, the cathodic protection system also causes a calcarious deposit to form over the bare steel areas. This calcarious deposit acts as a protective barrier and reduces the demand and depletion of the anode. Together, the coating and cathodic protection system are complimentary and increase the life of either system used independently. This point has been borne out in the test program.

1.1.2 Preconstruction Primer with Cathodic Protection

Many shipyards automatically abrasive blast and prime structural steel with an inorganic zinc shop primer prior to fabrication. This primer is normally removed from ballast tank surfaces and replaced with a high performance epoxy tank coating system. If the tank coating system could be eliminated and the

preconstruction primer left in place, new construction cost could be decreased. This approach was selected as one of the original test systems. An ethyl silicate inorganic zinc shop primer (85% zinc in the dry film) was applied to the steel substrate at a dry film thickness of 1.6 to 2.0 roils prior to fabrication. Inorganic zinc was selected because this material has been shown to provide superior shipyard handling and corrosion protection during the fabrication sequence. The primer was not repaired after the test tank fabrication was complete. Three test tanks were constructed. Two of the tanks were outfitted with cathodic protection; one with a zinc anode and one with a proprietary aluminum anode. The primed only system lasted for three years; the primer plus aluminum anode lasted five years, but the primer with zinc anode lasted for eleven years. Calcareous deposits formed on the bare areas of all the zinc coated tanks to include the primed only tank.

Some NACE studies have shown that aluminum anodes can be used to protect zinc; however, the NACE table of Corrosion of Galvanic Couples in Sea Water shows zinc to preferentially corrode in a couple with aluminum alloys unless the surface area of the aluminum is large in relationship to the zinc surface area. The difference in the aluminum alloys shown in the table and aluminum anodes manufactured specifically for cathodic protection is that aluminum anodes are alloyed with metals which cause the anode to corrode preferentially. In the test program, the aluminum anode was initially protected by the zinc primer but as the calcarious deposit built up and passivated the zinc surface, the potential shifted, and the aluminum anode rapidly depleted.

The zinc anode and zinc primer acted together to passivate the surface and form a calcareous deposit on the un-repaired bare surface areas. The zinc primer acted to increase the effective surface area of the zinc anode which improved anode performance. This accounts for the increased performance of this system. In addition, the residual zinc primer behind the stiffeners provided protection to areas which may normally be masked or shielded from the anode.

1.1.3 Volatile Organic Compound (VOC) Compliant Coatings

New air quality management standards preclude the use of many of the formerly approved standard (Mil-P-23236) epoxy and zinc tank coating systems. Coupled with this development are tighter controls over the use of abrasive blasting to clean steel and the resultant removal and disposal of abrasive residue. Blast residue disposal cost generally exceed by many orders of magnitude the initial procurement cost of the abrasive. In answer to this challenge many paint manufacturers have developed new materials which are reported to provide satisfactory performance when applied over surfaces which have been hand or power tool cleaned. Two of these surface tolerant materials were selected to be tested in this

project. For comparison, the materials were applied over surfaces prepared by both abrasive blasting and hand cleaning. Previous NSRP studies of foreign high solids materials had shown these types of high solids materials to be brittle. This finding was somewhat substantiated by this study in that one material failed by cracking when applied at excessive dry film thicknesses. The coating is specified to be applied at 12 to 16 roils dry but was applied at 30 to 40 roils. As the tank bottom flexed during ballasting, the coating cracked. The U.S. Navy has also been actively involved in formulating new VOC compliant versions of Mil-P-24441. One of these formulations was included in the project.

1.1.4 Anodes Added to Existinq Coated Tank

The Japanese have a method of extending the useful life of corrosion control coatings which consists of adding a zinc anode in lieu of performing coating repairs. During new construction ballast tanks are coated with a high performance coating system. After six to eight years, zinc anodes are added in lieu of coating repair or replacement. This has been reported to extend the life of the coating system another eight to ten years. By replacing anodes as anode depletion occurs, the coating system life can extended for the life of the vessel. The important point is to replace anodes on a regular basis before major steel failure takes place.

The coating system, even if failed as much as twenty-five to fifty percent, reduces anode demand and resultant consumption as compared to a totally bare tank. As the anode causes calcareous deposits to form, anode demand is again reduced, and anode life is extended.

1.2 Test Tank Facilities

To verify the relative performance of each corrosion control alternates and the compatibility of cathodic protection anodes with the various coating systems, three ballast tank test assemblies were fabricated from ASTM A-36, 1/4 inch thick hot rolled steel plate and shapes. The dimensions of each tank assembly was twelve feet long by four feet wide and four feet high. Each tank assembly was divided into three separate test cells for a total of nine test tanks. Each tank assembly was constructed to simulate the internal geometry of an actual ballast tank to include angles, built up frames and wide flanges. One side of each tank was of bolted construction to allow access for coating application and inspection.

Following tank fabrication and application of each corrosion control system, the tanks were ballasted and de-ballasted with fresh sea water (See Table 1). Each ballast cycle consisted of twenty days full and ten days empty.

TABLE 1
TEST SITE SEAWATER POLLUTION

Water Resistivity Ranged From 26 to 29 ohm/ cm	SPRING		SUMMER			FALL		
	MIN	MAX	MIN					
Water TemPerature ‘C	17	20	26			30	14	25
pH	6.5	7.5	7.6	8.3	6.7	8.1	7.2	8.2
Dissolved Oxygen	5.8	8.5	4.2	7.8	4.2	7.6	5.2	9.4
Salinity (Parts per 1000)	18	29	22	36	6	33	9	27

1.3 Surface Preparation and System Application

Table 2 contains a listing of those systems currently under test to include surface preparation. During abrasive blast surface preparation it was difficult to achieve a true SSPC-SP 10, “Near White Blast Clean" surface. Due to the apparent high chloride contamination of the corroded steel, the blasted surface would flash rust within a matter of minutes. This statement wholes true for all the tanks which were reblasted for this phase of the project. No attempt was made to remove the chloride contamination other than that accomplished by the surface preparation technique.

During initial surface preparation in 1980, no flash rusting was observed. A Starolite mineral abrasive was used at that time. Sand or coal slag (#1240) was used for replacement and repairs. Sand was used to initially blast each tank with coal slag being used as the last step to impart a profile. Difficulty was also experienced achieving a proper blast behind stiffeners and structure.

Hand and power tool cleaning consisted of chipping hammers, hand and power wire brushes, needle guns and power disc sanders. Hand sanding was used to feather the edge of intact remaining coatings.

All coatings were applied with conventional pressure pots and spray guns. All welds and sharp edges were stripe coated before the application of the first coat and between coats.

TABLE 2-TANK COATING SYSTEMS INCLUDED IN TEST PROGRAM

TANK NO.	SURFACE PREPARATION	SYSTEM DESCRIPTION	ANODE	SYSTEM AGE	PERFORMANCE SUMMARY
1	SP-2/SP-3	SURFACE TOLERANT VOC COMPLIANT EPOXY "A"	NONE	5 YEARS	20 TO 30% OVERALL FAILURE
2	SP-10	TOTALLY COATED WITH TWO COATS OF AMINE ADDUCT CURED MIL-P-23236. ANODE ADDED AFTER 6 YEARS.	ZINC	11 YEARS 5 WITH ANODE	SYSTEM CONTINUES TO PROVIDE PROTECTION WITH MINOR METAL LOSS. NO CHANGE FROM LAST REPORT.
3	SP-10	TOP AND BOTTOM COATED WITH TWO COATS OF AMINE ADUCT CURED MIL-P-23236. CENTER LEFT UNCOATED.	ZINC	11 YEARS	SYSTEM CONTINUES TO PROVIDE PROTECTION WITH MINOR METAL LOSS BUT ANODE IS AT USEFUL LIFE
4	SP-10	SURFACE TOLERANT VOC COMPLIANT EPOXY "A"	NONE	5 YEARS	10 TO 20% OVERALL FAILURE.
5	SP-6	SURFACE TOLERANT VOC COMPLIANT EPOXY "B". THIS SYSTEM WAS SP-2 REPAIRED AFTER 6 YEARS OF TESTING	NONE	8 TOTAL 2 WITH REPAIR	LESS THAN 1% FAILURE
6	SP-10	INORGANIC ZINC (85% ZINC) PRECONSTRUCTION PRIMER	ZINC	11 YEARS	ANODE FAILED. SYSTEM HAS FAILED.
7	SP-10	VOC COMPLIANT EPOXY TANK COATING, MIL-P-24441, TYPE 1	NONE	5 YEARS	LESS THAN 1% EXCEPT FOR STIFFENER EDGES AND LOWER 4" ON LEFT SIDE.
8	SP-10	HIGH RATIO WATER BORNE INORGANIC ZINC	NONE	1 YEAR	LESS THAN 1% EXCEPT FOR UNDER SIDE OF STIFFENERS
9	SP-1/SP-2	SURFACE TOLERANT VOC COMPLIANT EPOXY "B" REPAIRED AFTER 3 YEARS	NONE	5 YEARS	REPAIR COAT DELAMINATING FROM ORIGINAL COAT. LESS THAN 5% OVERALL FAILURE.

2. TEST RESULTS

2.1 Performance of Zinc Anode with Partial Coatings

After eleven years of testing, Tank 3 is still providing protection to the steel substrate; however, the zinc anode (5o pound) is nearing useful anode life. This system was originally designed to last for four years. The original aluminum anode (20 pound) system was also designed for four years and lasted for six years. The color of the bare portion of the tank is the color of the calcareous deposit with possibly some red color being picked up due to the system beginning to fail. No metal loss was detected.

2.2 Performance of the Zinc anode with Preconstruction Primer

After eleven years Tank 6 has failed. The anode is depleted; however, some of the calcareous deposit is providing a degree of protection. Some metal loss was observed.

2.3 Performance of the Aged Coating System with Added Zinc Anode

No change was noted in Tank 2. No new coating failure was detected. Calcareous deposits continue to increase. Very little anode consumption was noted. This system is eleven years old. A zinc anode was added after six years.

2.4 Performance of Epoxy "A" Over Blast Cleaned Steel

Tank 4 has reached the useful life of the coating system after five years of testing with the overall failure judged to be ten to twenty percent. The performance of this system over blast cleaned steel is marginally better than the same system applied over hand and power tool cleaned steel.

The back of the tank had twenty percent coatings failure with the top stiffener beginning to exfoliate due to massive rusting. The bottom stiffener had thirty percent failure but no exfoliation. The left side and flat top had ten percent coatings failure. The edge of center top stiffener was also exfoliating. The right side had five percent failure, and the flat bottom had one percent failure. The bottom built up frame was exfoliating on the edges but the flat surfaces had less than one percent failure.

In summary, this system provided good protection on flat surfaces but poor edge protection. As discussed in the section on surface preparation and application, all edges and welds were stripe coated.

2.5 Performance of Epoxy "A" Over Hand Cleaned Steel

After five years Tank 1 performed somewhat poorer than Tank 4; however, at the end of three years, Tank 1 was a little better than

Tank 4. This difference cannot be plained. The primary areas of inferior performance were on the sides of the tank. Whereas Tank 4 had only five and ten percent failure on each side respectively, Tank 1 had thirty percent failure. The bottom of Tank 1, except for the built up frame, had approximately the same degree of failure as Tank 4. The flats on the frame were equal to Tank 4 but the edges had less exfoliation. The flat top and stiffener was better than Tank 4. This is probably due to the fact that the overhead in Tank 1 still had the intact, original coating of amine adduct cured epoxy when the new test system was applied.

In summary it would be difficult to use the performance results of this system applied over hand tool cleaned steel verses the performance of the same system applied over abrasive blast cleaned steel to justify abrasive blasting. Both techniques provided comparable protection to the steel during the test cycle, and both systems require extensive repair or replacement prior to continuing the project.

2.6 Performance of Epoxy "B" Applied Over Blast Cleaned Steel

Tank 5 has been under test for a total eight years. After six years of testing, the system was repaired using hand tool cleaning (SSPC-SP 2) . Following the initial six years of testing, this system was beginning to show significant breakdown. The top of the tank had twenty-five to fifty percent failure. The right side of the tank had totally failed. The balance of the tank had between five and ten percent failure.

The repair system is two years old at the time of this report. The overall failure is less than one percent with only minor breakdown on the edges of the overhead stiffener. No failure was observed on the balance of the structure. The residue from the ballast operations should be disregarded when viewing the photograph of this tank.

2.7 Performance of Epoxy "B" Applied Over Solvent and Hand Tool Cleaned Steel

The system in Tank 9 has been in service for five years. At the end of three years of testing, this system had cracked and delaminated in some areas due to excessive dry film thickness (30 to 40 mils). No failure was observed except for these cracks and associated delamination.

At the conclusion of three years, a decision was made to repair this system. The failed portion of the coating was removed and the same material reapplied. After two additional years, the coating is again beginning to crack and delaminate though not as severe as the first time. Some minor edge breakdown was also noted. The overall failure is less than five percent.

2.8 Performance of VOC Compliant Version of Mil-P-24441 Over Blast Cleaned Steel

Except for some edge breakdown and the lower four inches on one side of the tank, the coating system in Tank 7 is providing corrosion protection after five years of testing. The overall failure is less than one percent. The top stiffener is beginning to exfoliate as is the edge of the bottom stiffener. The lower four inches on the left side has seventy-five percent failure.

2.9 Performance of Waterborne Zinc Over Blast Cleaned Steel

The high ratio inorganic zinc coating applied in Tank 8 has been under test for one year. Except for the underside of stiffeners, the overall performance was an ASTM D 610 rust grade 9 or better. A rust grade 9 equates to less than 0.03 percent visible rust. The only areas of failure was noted on the underside of stiffeners. Even though the coating had appeared to delaminate in approximately ten percent of the underside area, no rust was visible.

3. PROJECT BENEFITS

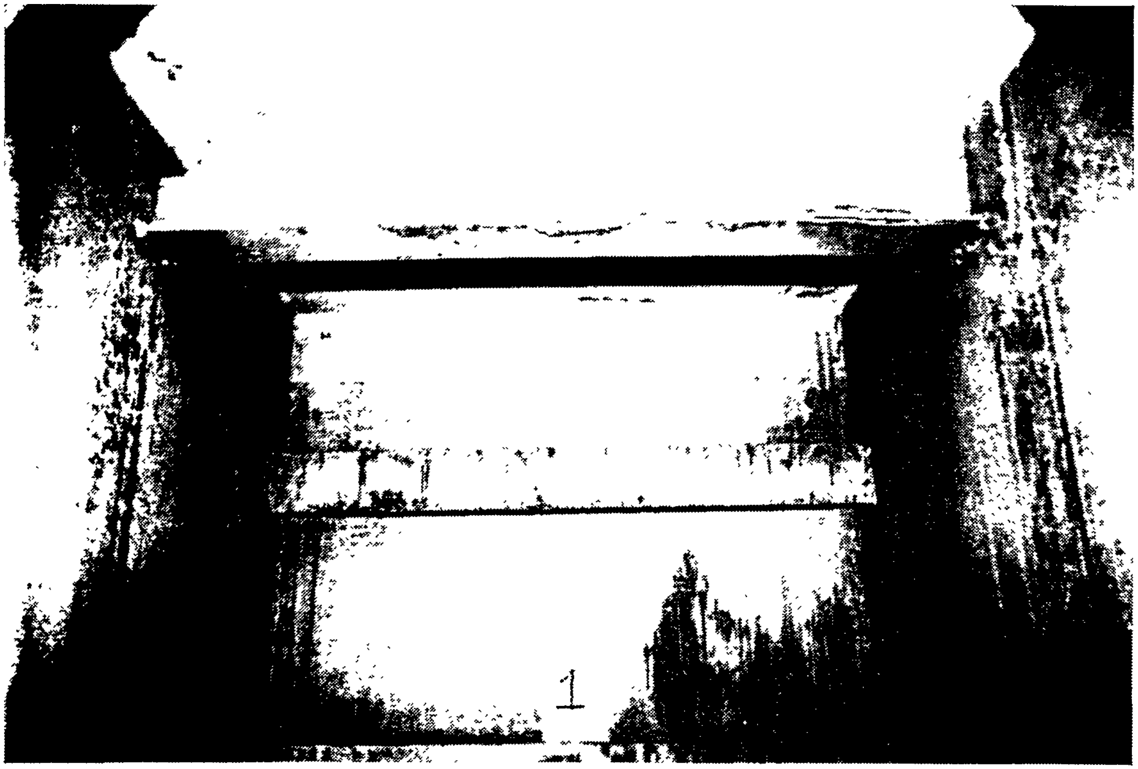
Four direct benefits can be realized from the results of this project. These include:

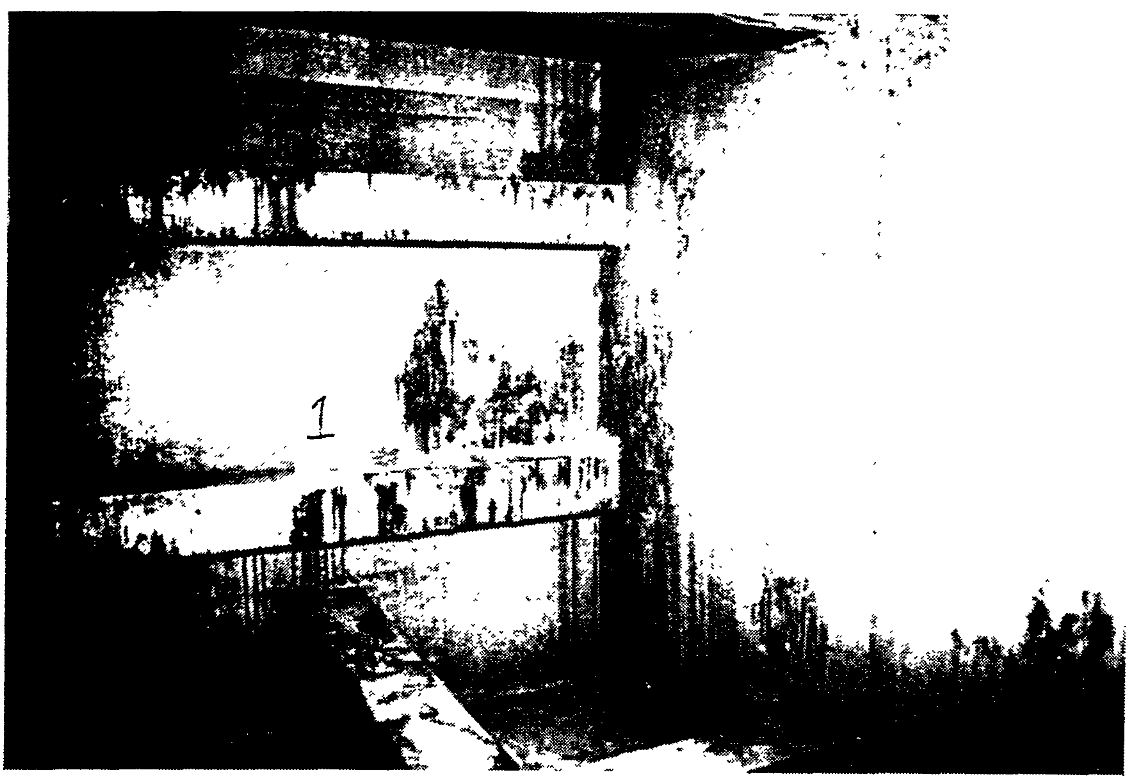
- The use of surface-tolerant epoxy systems for either touch-up and repair of existing systems or as total replacement systems applied over what has previously been considered substandard surface preparation, i.e. , hand or power tool cleaning, has the potential to significantly reduce the cost of maintaining ship's ballast tanks.

- Verification that zinc anodes, or other cathodic protection, can be added to partially failed, existing coating systems in lieu of coating repair or replacement. The cost of zinc anodes installation should be significantly less than coating replacement. Also, the generation of toxic and hazardous waste from tank coating operations would be eliminated.

- Verification that full thickness inorganic zinc with or without cathodic protection can significantly extend the repair or replacement cycle for ballast tank coating systems.

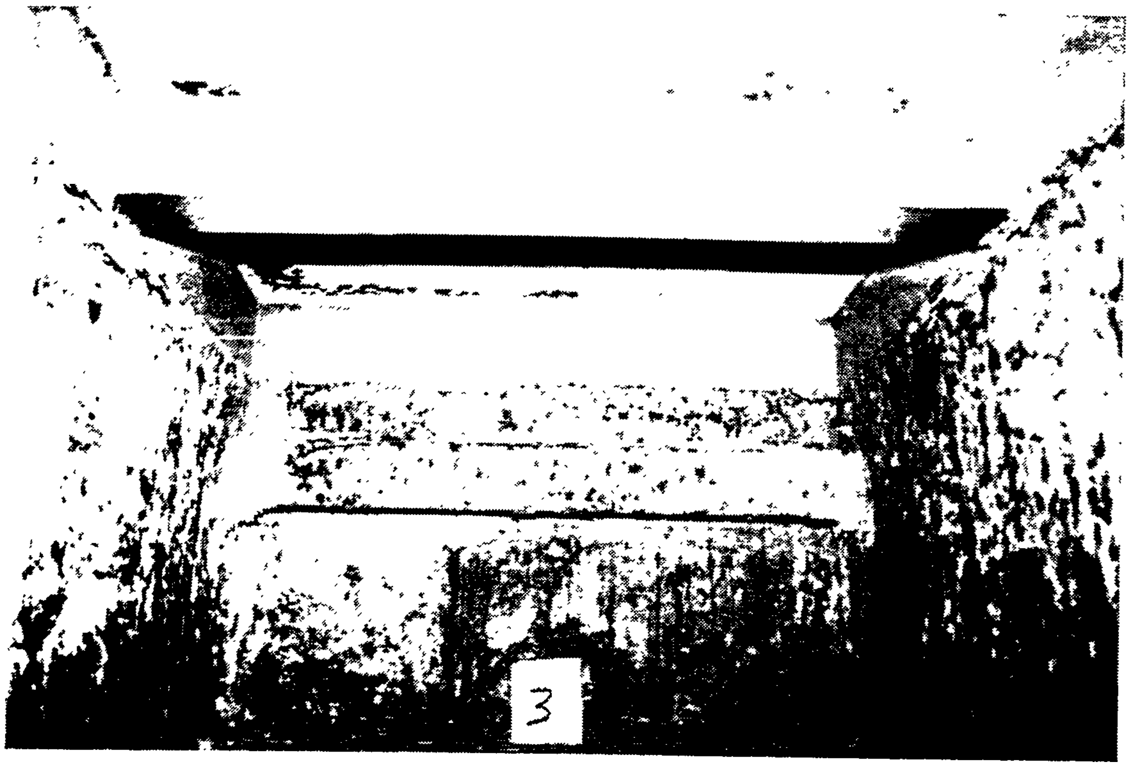
- Inorganic zinc primer with zinc anodes can provide extended ballast tank coating system life at reduced initial installation cost.



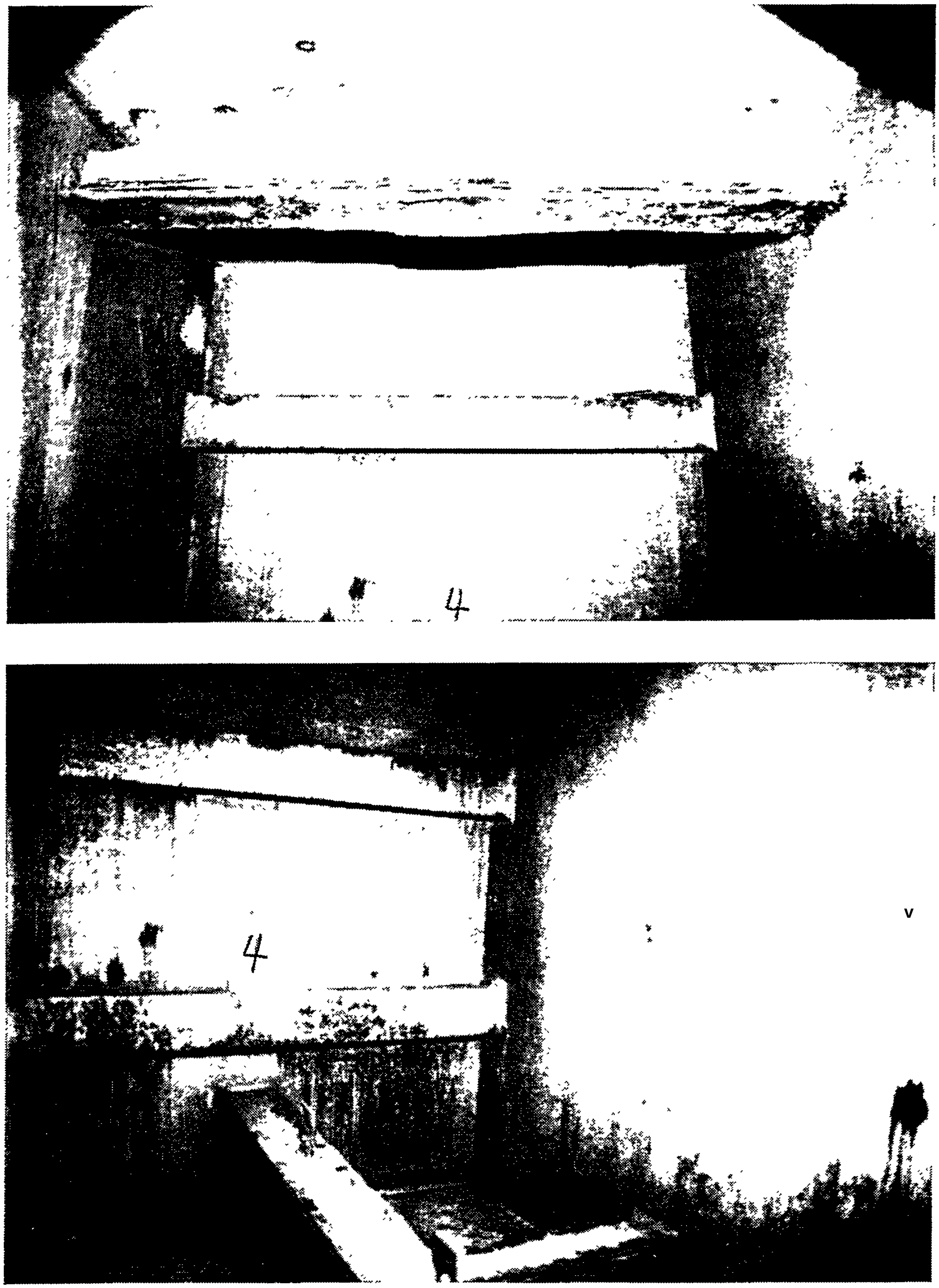


Tank l-Epoxy "A" Over Hand Tool Cleaned Surface (5 Years)

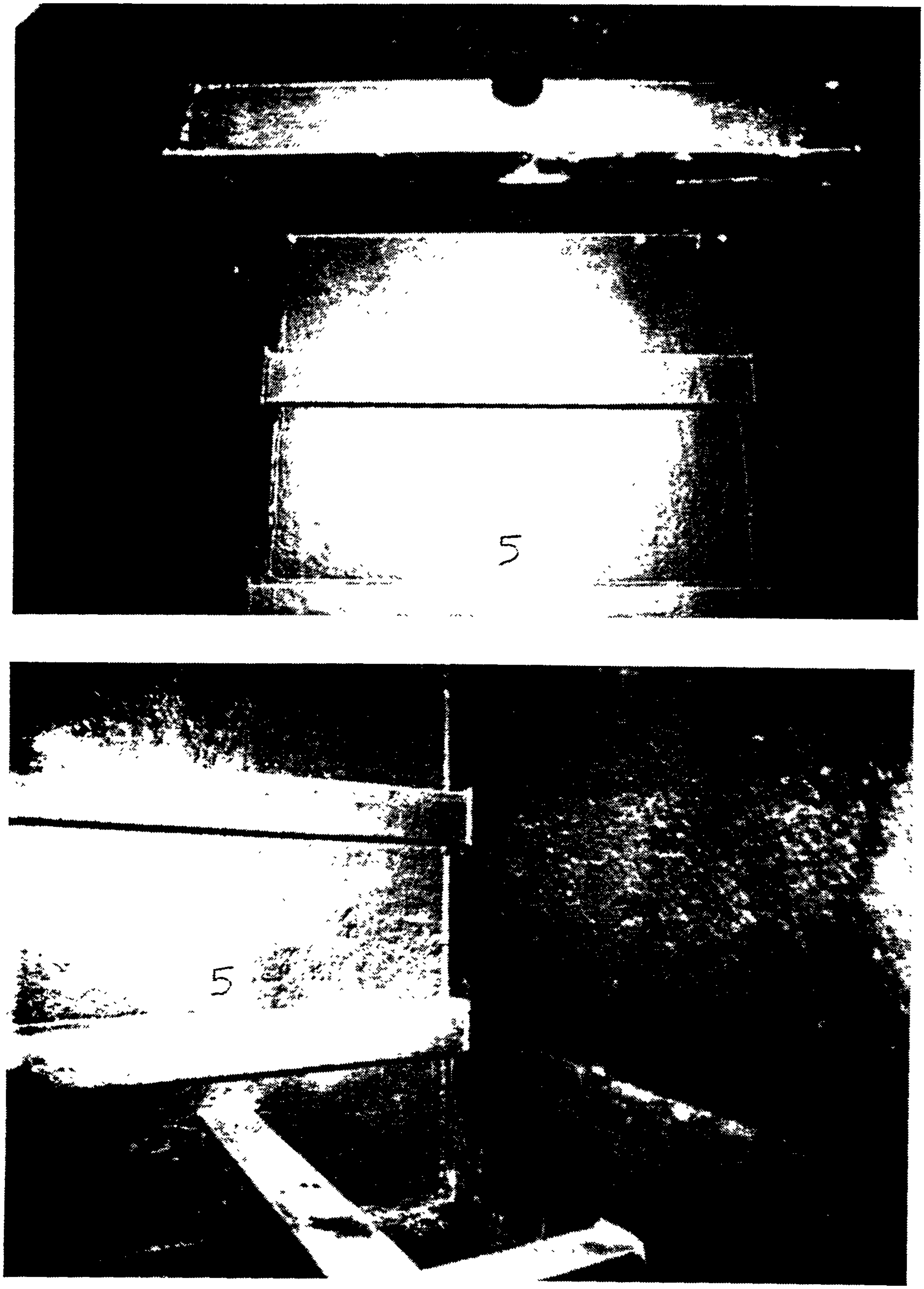
Tank 2- Mil-P-23236 Coating with Added Zinc Anode (11 Years)



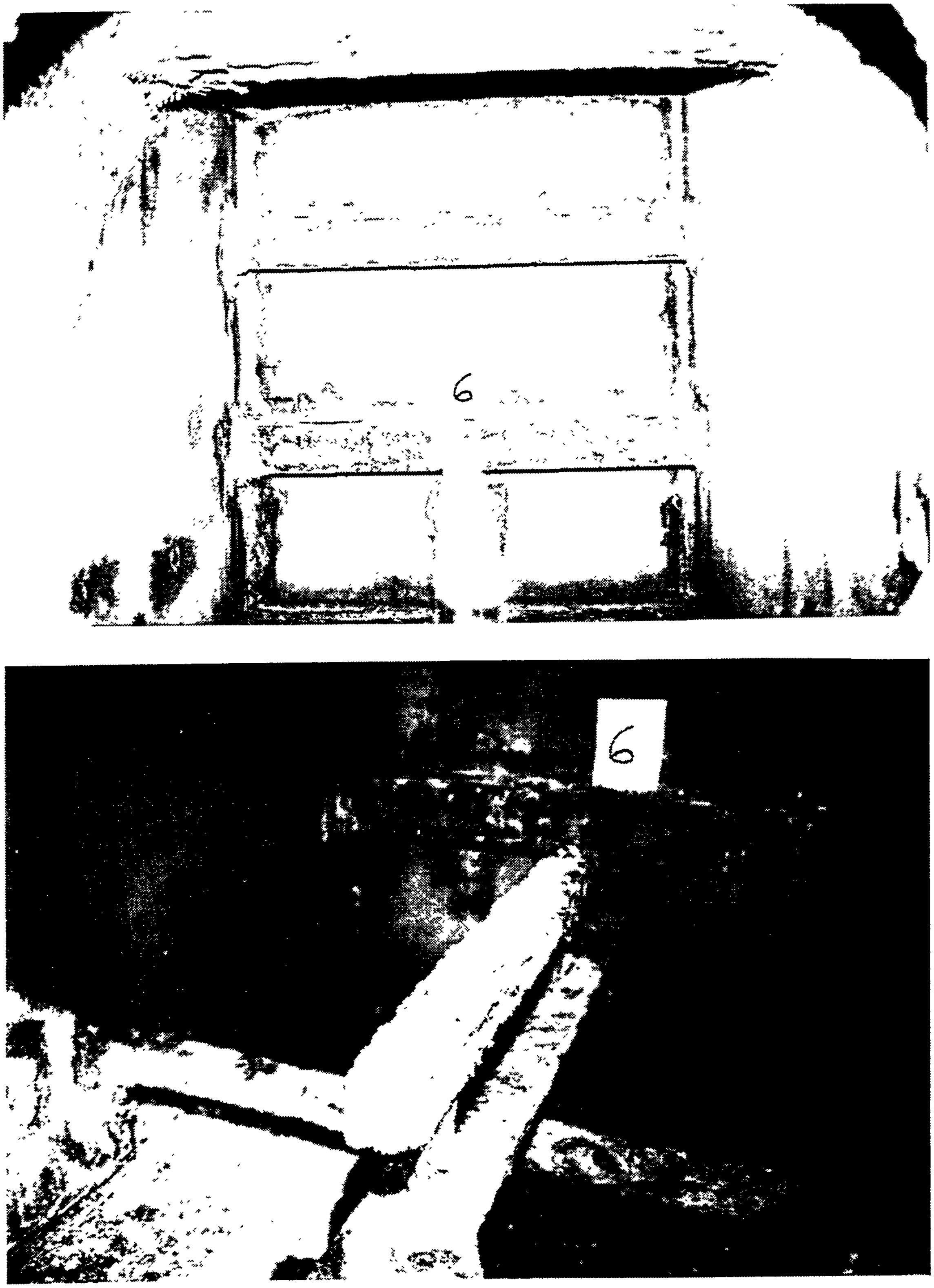
Tank 3-Partial Coating with Zinc Anode (11 Years)



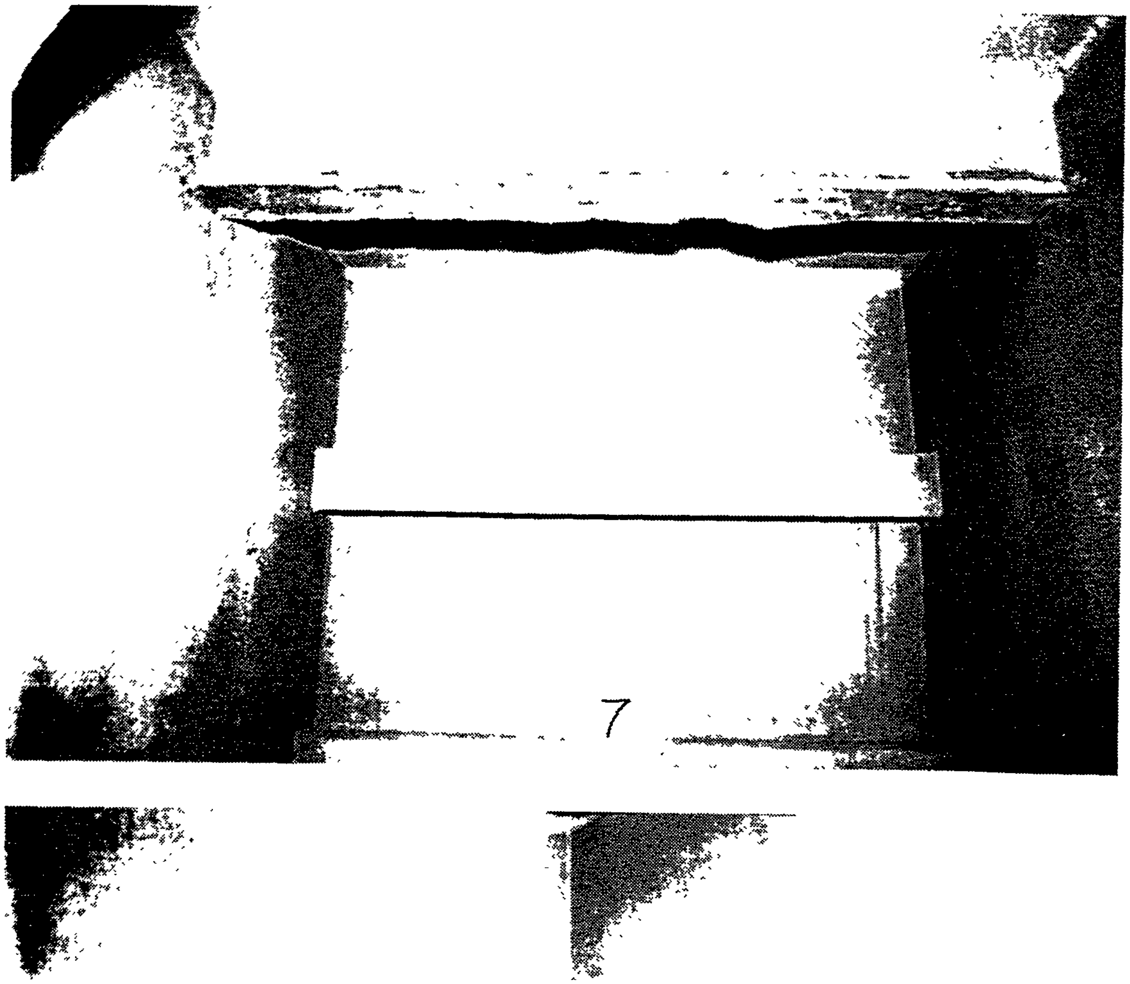
Tank 4-Epoxy "A" Over Blast Cleaned Surface (5 Years)

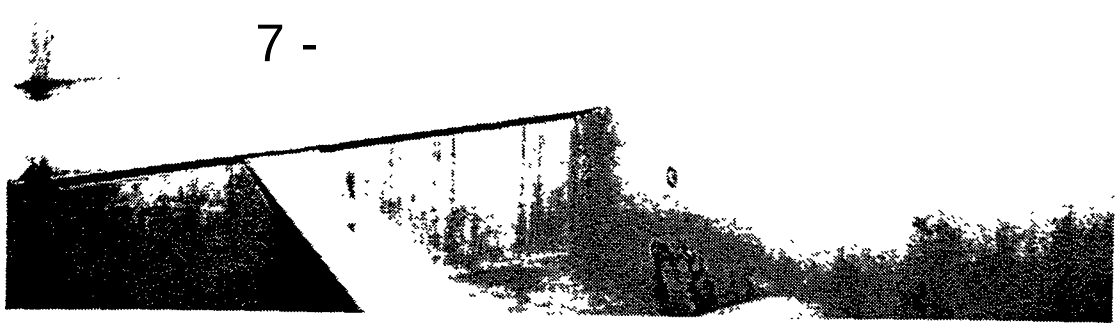


Tank 5-Epoxy "B" Over Blasted (SP6) Surface (2 Years After Repair)

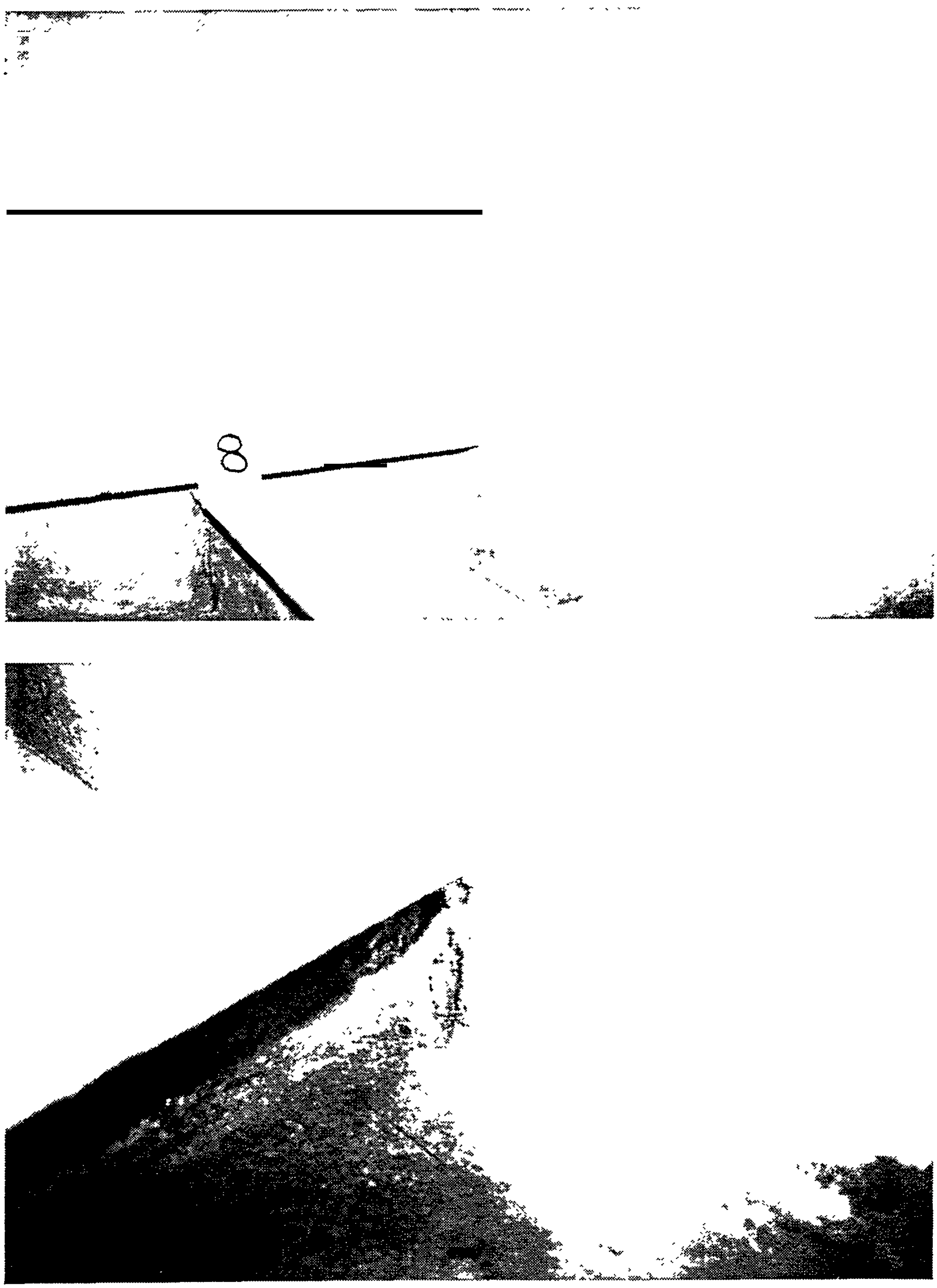


Tank 6-Preconstruction Primer with Zinc Anode (11 Years)

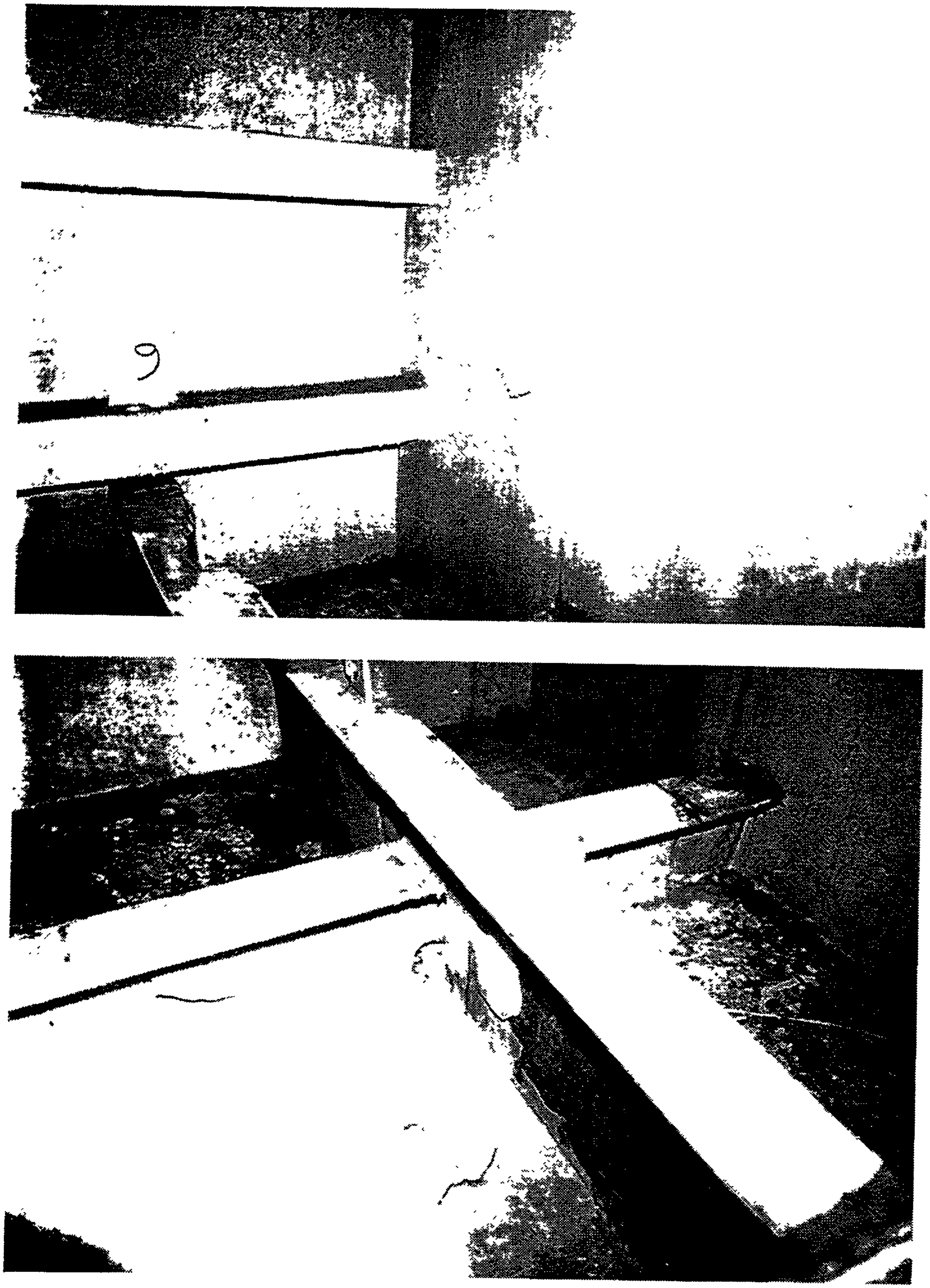




Tank 7-VOC Compliant Mil-P-24441 Over Blast Surface (5 Years)



Tank 8-High Ratio Waterborne Inorganic Zinc (1 Year)



Tank 9- Epoxy "B" Over Hand Tool Surface (2 Years After Repair)

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